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DISCUSSION

THE ROLE OF DAMPING IN SEISMIC ISOLATION

DISCUSSION BY JOHN F. HALL*
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The writer disagrees with some opinions expressed by Professor James Kelly in 'The Role of Damping in Seismic Isolation'. (*Earthquake Engng Struct. Dyn.*, **28:** 3–20 (1999)). His assertion that the 1997 Uniform Building Code sets excessive design displacements for base isolators is not justified in the paper. There is only a statement that the code's near-source factors make it difficult and expensive to design an isolated building for a site close to a major fault. This linkage between the validity of the code's quantification of seismic effects and the expense of meeting the code is dangerous in the writer's opinion. The reality is that big earthquakes produce large, rapid ground displacements and significant long-period content, especially as associated with near-source effects, which impose high demands on flexible structures, including isolation systems.[1,2] In the paper, the reality of near-source effects is reduced to 'some evidence for pulse-type motion … in the Sylmar ground motion record in the 1994 Northridge, California earthquake'. As for the rationale behind the trend in the UBC towards more conservative isolator design, the author refers only to an 'attack' (e.g., references 1 and 2) on the 'efficacy of seismic isolation technology' by a group of 'seismologists' whose 'misunderstandings' and 'flawed models' have 'nevertheless … influenced the design of base-isolated buildings in California'. Such comments are unfortunate because they misrepresent previous studies of the performance of earlier base-isolated designs to strong near-source ground motions and because they discredit the responsible efforts of code writers.

The main objective of the paper is to argue against the use of supplemental damping to reduce the large design displacements of the isolators because, although this reduction is desirable and allowed by the code, it comes at the 'expense of increasing floor accelerations and interstorey drifts'. To demonstrate and quantify possible detrimental effects of supplemental damping, the author presents an analytical treatment of a linear two-degree-of-freedom example base-isolated structure (Figure 1) for two amounts of damping β_b associated with the isolation system. With β_b equal to 10 and 50 per cent of critical (as computed for a nominal mode in which the structure is rigid above the isolators), the author concludes that 50 per cent damping does have significant detrimental effects on acceleration and drift. In addition, he seems opposed to any amount of supplemental damping, dismissing the concept as 'a misplaced effort' and 'self-defeating'.

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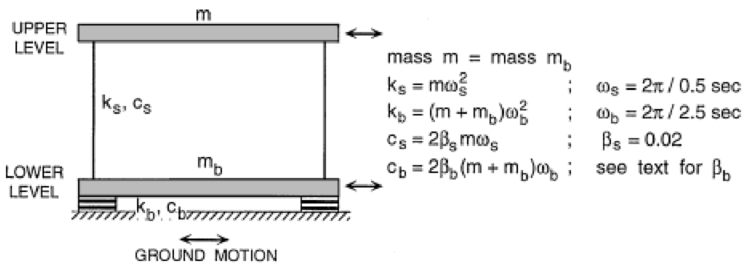

Figure 1. Linear two-degree-of-freedom example base-isolated structure. k_s, k_b = stiffnesses of structure and isolation system. c_s, c_b = coefficients of viscous damping for structure and isolation system

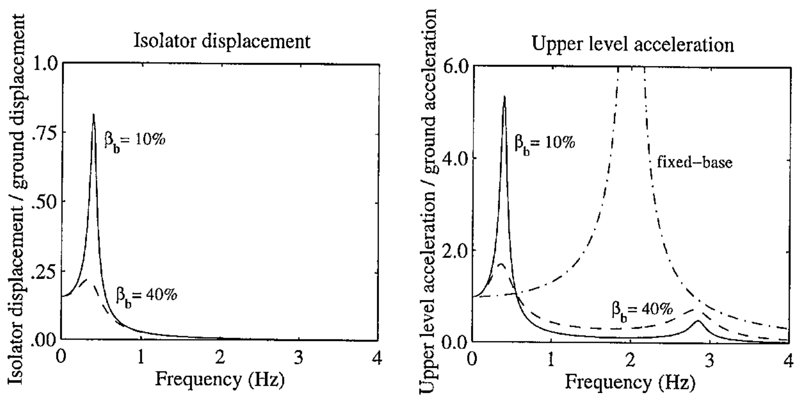

Figure 2. Frequency response amplification curves for isolator displacement and upper level acceleration

The author's analysis, which makes numerous assumptions whose effects *in toto* are hard to judge, can be supplemented by more direct approaches. For the same example problem (Figure 1), amplification factors for isolator displacement and upper level acceleration as a function of frequency (frequency response curves) are computed and shown in Figure 2. Levels of damping β_b are chosen as 10 and 40 per cent; the fixed-base case is also included. In the figure, the first resonance is essentially that of a rigid structure on the flexible isolators, and the amplitude reduces significantly when a substantial amount of supplemental damping ($\beta_b = 40$ per cent) is included. The second mode resonance is affected in a more complicated way with the larger β_b producing an increase in the participation factor as well as in the effective modal damping; the result is a broadening of the resonance peak with some increase in peak amplitude. The usefulness of Figure 2 is that it indicates how effects of adding supplemental damping are related to the frequency content of ground motion. An excitation consisting of mainly high frequencies could produce perhaps twice the upper level acceleration for $\beta_b = 40$ per cent compared to $\beta_b = 10$ per cent, but this amplified motion would still be far below the response of the fixed-base structure. For a ground motion with low-frequency components present, larger β_b significantly reduces the isolator displacement, and, depending on particulars of the ground motion, the effect on the

Table I. Computed peak responses of the example isolated structure to three ground motions

Amount of damping β_b (%)	Isolator displacement (cm)	Storey drift (cm)	Upper level acceleration (cm/sec^2)
Bonds Corner, 1979 Imperial Valley earthquake			
10·0	10·0	0·82	129·0
20·0	9·0	1·08	171·0
30·0	8·0	1·38	218·0
40·0	8·0	1·65	261·0
Fixed-base	0·0	11·00	1740·0
Olive View Hospital free field, Northridge earthquake			
10·0	61·0	2·66	420·0
20·0	47·0	2·67	421·0
30·0	38·0	2·62	413·0
40·0	32·0	3·01	476·0
Fixed-base	0·0	12·70	2000·0
Takatori, Kobe earthquake			
10·0	84·0	3·53	558·0
20·0	65·0	3·17	501·0
30·0	57·0	3·18	501·0
40·0	50·0	3·33	525·0
Fixed-base	0·0	10·40	1650·0

upper level acceleration could be either favourable or unfavorable, but probably only moderately so either way.

Table I shows peak values of isolator displacement, interstorey drift and upper level acceleration computed for three sample ground motions. Results are included for $\beta_b = 10$, 20, 30 and 40 per cent. For the 1979 $M_W 6{\cdot}4$ Imperial Valley record at Bonds Corner (component 230°, peak ground acceleration of 0·78g), a fairly intense high-frequency motion, increasing β_b from 10 to 40 per cent doubles the peak drift and acceleration, as predicted from Figure 2. However, these values are still reasonably small, and a comparison to the fixed-base case shows that the structure remains relatively well isolated. The other two records contain high-frequency motion as well as significant lower frequency components from near-source effects. For both, the horizontal component considered is the one having the largest peak-to-peak ground velocity. In the case of the 1994 $M_W 6{\cdot}7$ Northridge earthquake motion at Sylmar (Olive View Hospital free-field, peak ground acceleration of 0·83g), the 30% value of β_b reduces the maximum isolator displacement to 38 cm from the 61 cm at $\beta_b = 10$ per cent, while leaving the structural response unchanged. Increasing β_b to 40% further reduces the maximum isolator displacement to 32 cm, with only a minor penalty to drift and acceleration of the structure. Favorable results are also obtained for an even stronger near-source ground motion, Takatori (peak ground acceleration of 0·75g) from the 1995 $M_W 6{\cdot}9$ Kobe earthquake. In this case, the maximum isolator displacement is decreased from the very large value of 84 cm at $\beta_b = 10$ per cent to a more manageable 57 cm at $\beta_b = 30$ per cent, with a further reduction to 50 cm at $\beta_b = 40$ per cent, all with essentially no increase in drift and acceleration of the structure.

Many other earthquake records tried by the writer exhibit similar trends to those of Table I. All of these results clearly suggest that some use of supplemental damping is an essential part of an

isolation system when strong ground shaking containing near-source effects is possible at a site. The optimal amount is a function of many factors including economic ones. Certainly, the brief study described here should be extended to more realistic structural models, especially as characterized by more degrees of freedom and by accurate non-linear treatment of the isolation system.

The author's proposed solution for limiting the isolator displacements in the large event, in lieu of supplemental dampers, is to use natural restraint in the isolators from either stiffening in rubber pads at large shear strains or by an increase in the curvature of the sliding surface in a frictional device. However, any possible detrimental effects of properly designed supplemental dampers would be less severe than if such restraints were reached. A paper supporting this opinion and examining the various approaches is being prepared by the writer.[3] In that paper, both the isolation system and superstructure are treated as non-linear, and some ground motions from earthquakes larger than the ones considered here are employed. An additional parameter examined is the required code strength of the superstructure as effected by use of supplemental damping to reduce the isolator design displacement.

In conclusion, the author needs to provide more convincing evidence of his view that 'the effort to improve performance ... by adding damping is a misplaced effort and inevitably self-defeating'. The position of the writer is the opposite. Consideration of the various tradeoffs would seem to favor the use of some supplemental damping with isolation systems in near-fault locations. Many designers have also reached this conclusion.

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